(12) UK Patent Application (19) GB (11) 2 360 425 (13) A

(43) Date of A Publication 19.09.2001

(21) Application No 0006181.2

(22) Date of Filing 16.03.2000

(71) Applicant(s)
Siemens Aktiengesellschaft
(Incorporated in the Federal Republic of Germany)
Wittelsbacherplatz 2, D-80333 München,
Federal Republic of Germany

(72) Inventor(s)
Jens Plogsties
Germano Dolso
Monguzzi Giulio

(74) Agent and/or Address for Service
M Kay Ross
Siemens Shared Services Limited, Intellectual Property Department, Siemens House, Oldbury, BRACKNELL, Berkshire, RG12 8FZ, United Kingdom

(51) INT CL[7]
H04L 25/03, H03M 13/45, H04L 1/00 // H03M 13/29

(52) UK CL (Edition S)
H4P PRE

(56) Documents Cited
GB 2271916 A EP 0948140 A1 EP 0802656 A2
EP 0550143 A2 US 5285480 A

(58) Field of Search
UK CL (Edition R) H4P PRE PRV
INT CL[7] H03M 13/29 13/39 13/41 13/45, H04L 1/00 25/02 25/03
Online: EPODOC, JAPIO, WPI

(54) Abstract Title
Channel state information estimation for turbo-code decoders

(57) The performance of turbo-code decoders employing Maximum A Posteriori probability decoding algorithms is dependent upon the integrity of channel state information. Known decoders use hard decisions based upon soft decision outputs of a demodulator in order to determine channel state information. The present invention improves upon this technique by re-estimating channel state information using output data bits generated by the turbo-code decoder (500) and fed back to the channel state information estimation unit (402) via encoder (414). The re-estimation is repeated iteratively until there is no improvement in the decoded data (see Fig. 6). The channel state information estimation unit (402) employs a minimum variance unbiased estimation technique to iteratively estimate the mean and variance of noise components of soft decision outputs of the demodulator. The decoder is applicable to cellular communications such as UMTS.

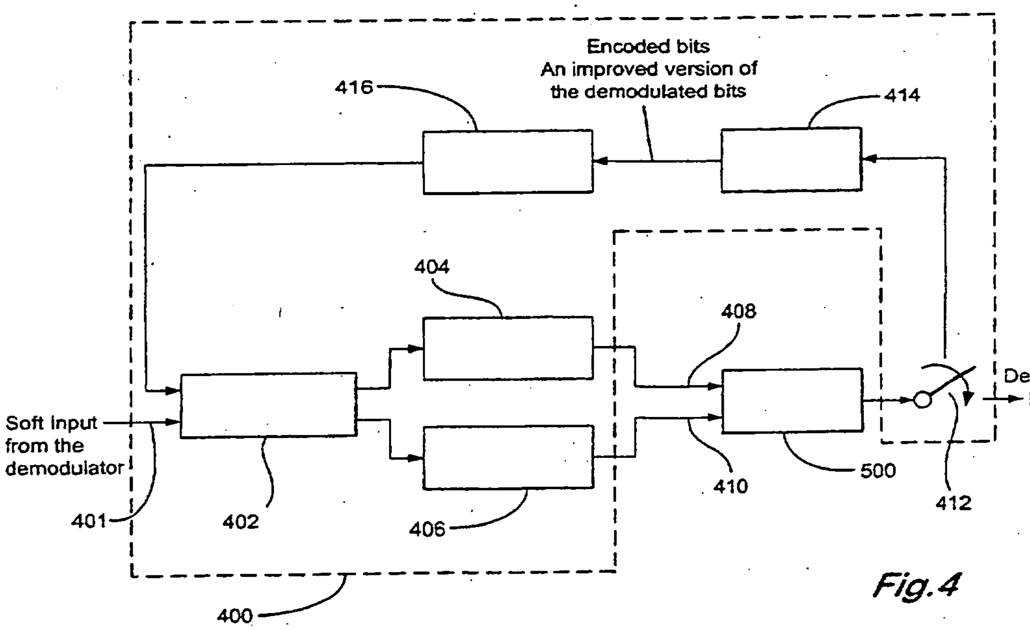
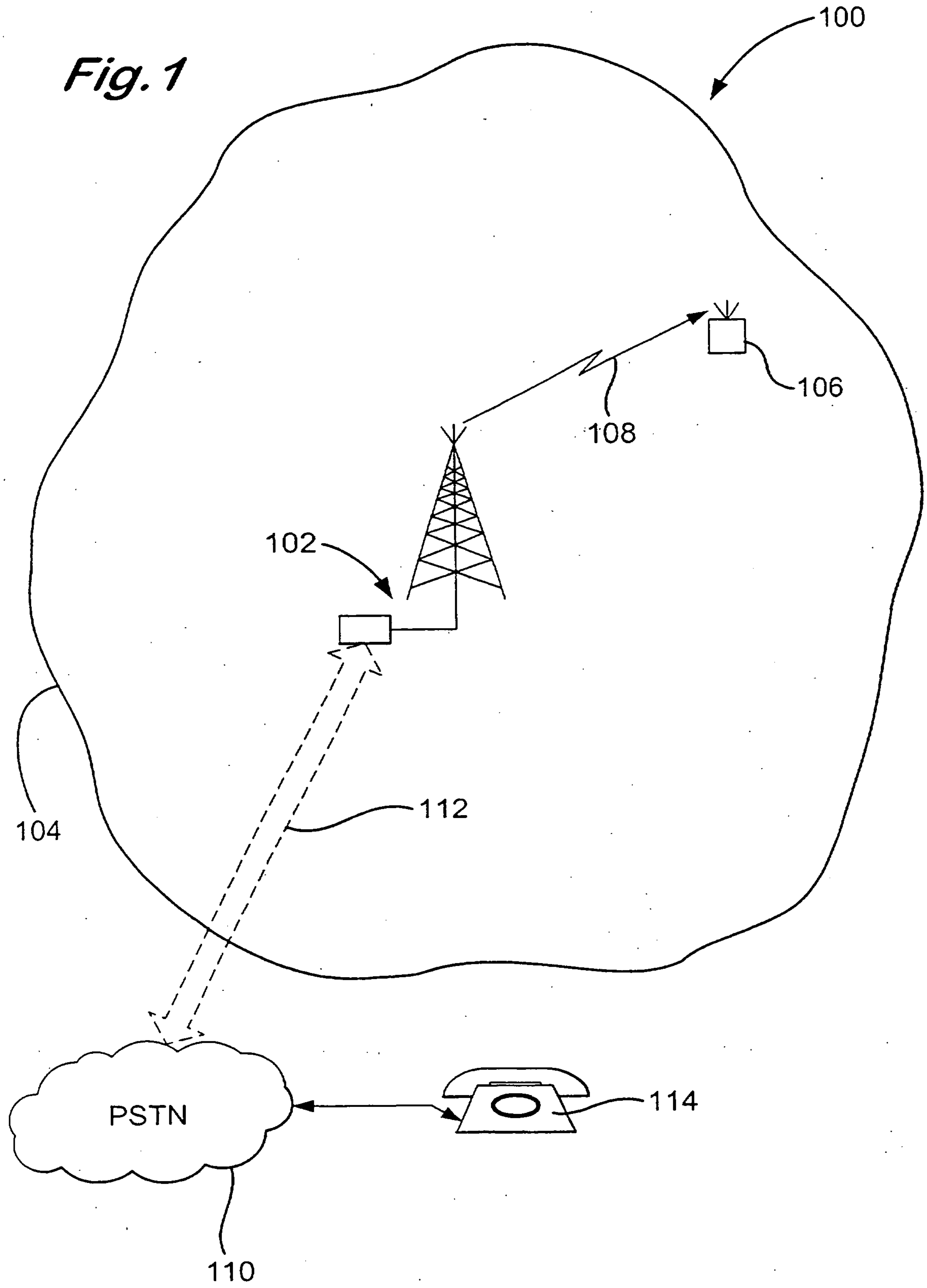


Fig.4

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

GB 2 360 425 A

Fig.1



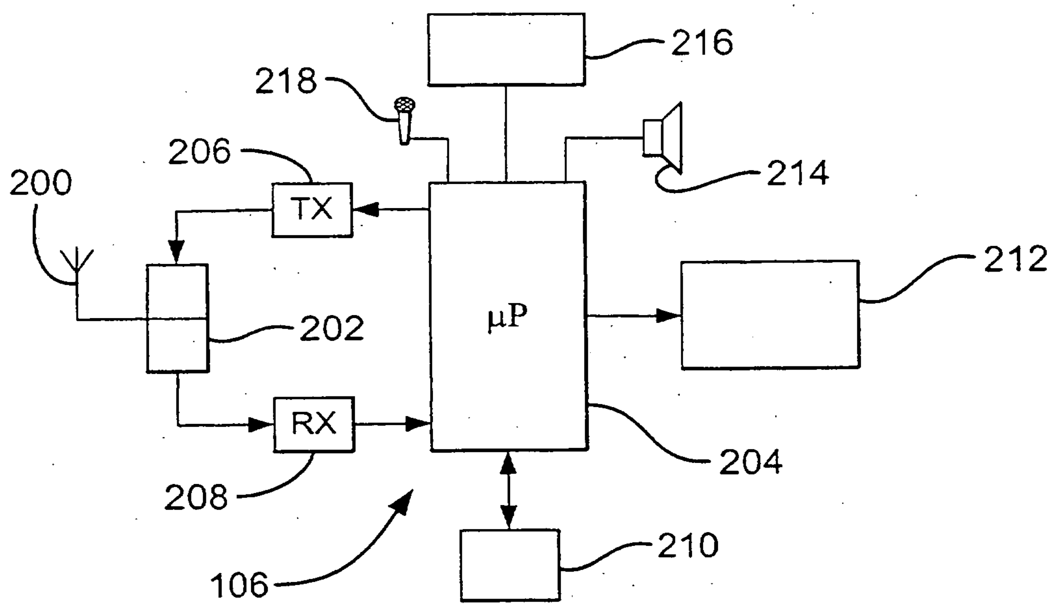

216
218
206
200
TX
214
212
μP
202
RX
204
208
210
106

Fig.2

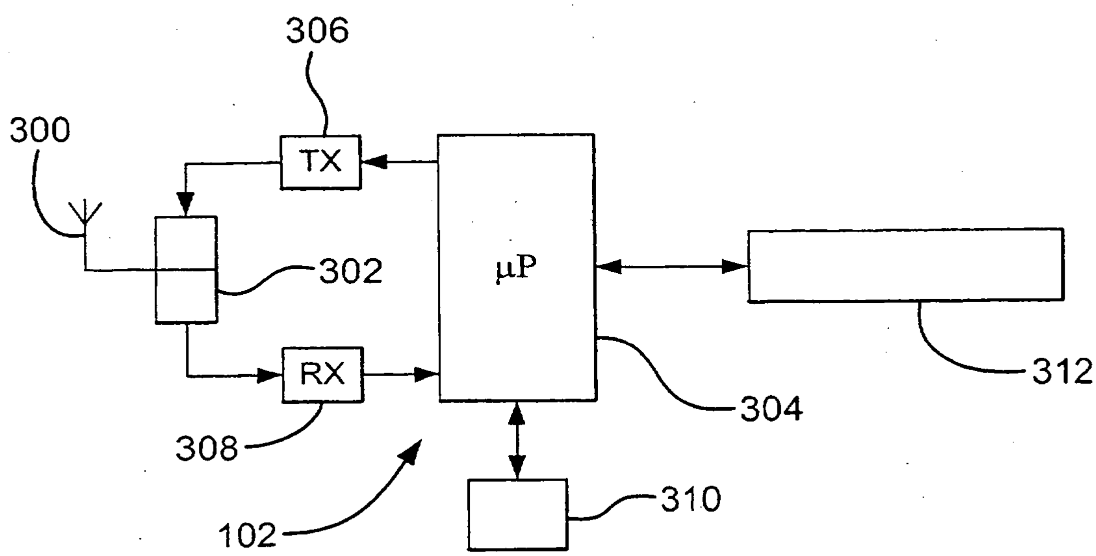

306
300
TX
302
μP
RX
312
304
308
310
102

Fig.3

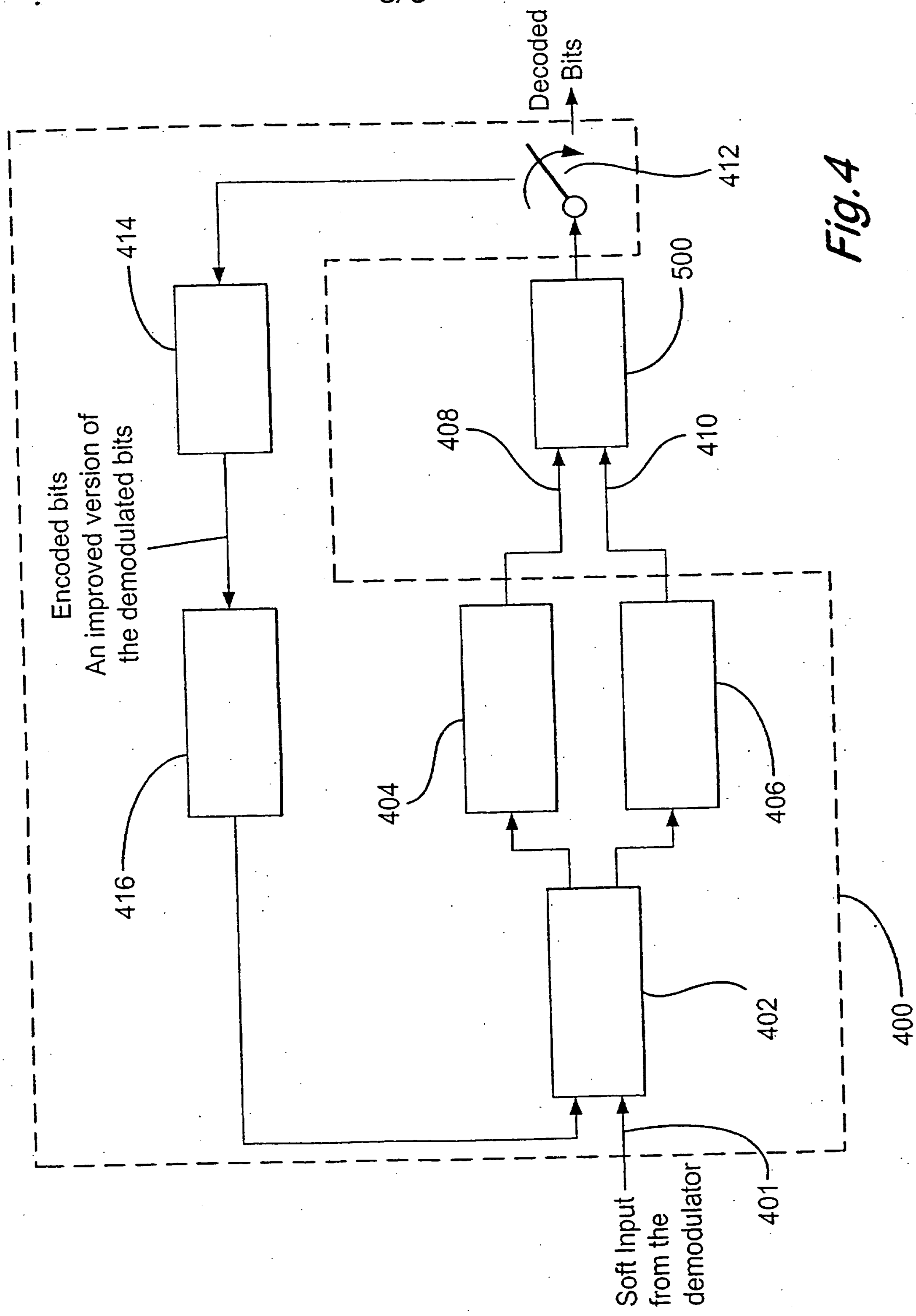
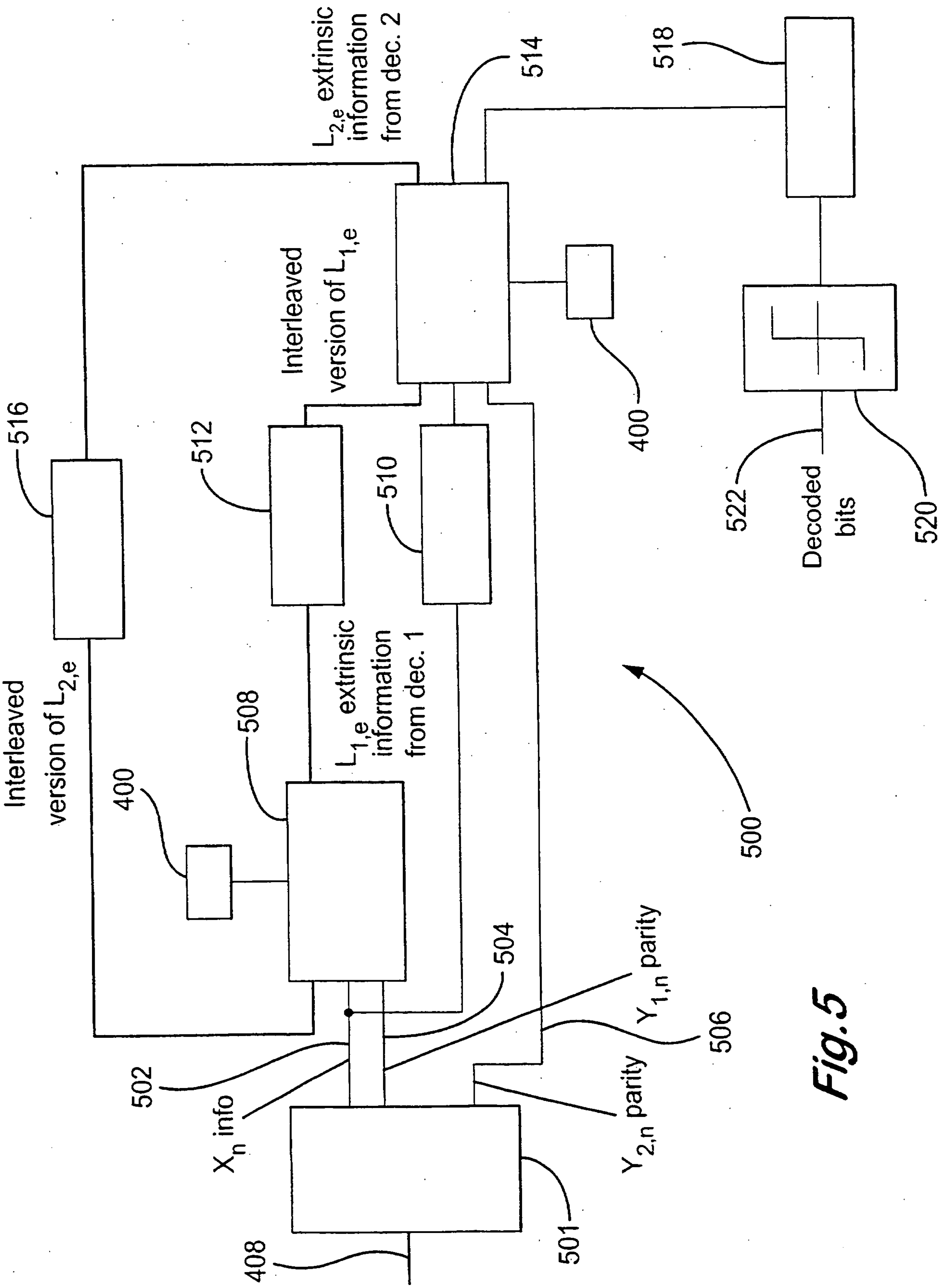

Decoded Bits
412
414
500
408
410
Encoded bits
An improved version of the demodulated bits
404
406
416
402
400
Soft Input from the demodulator
401

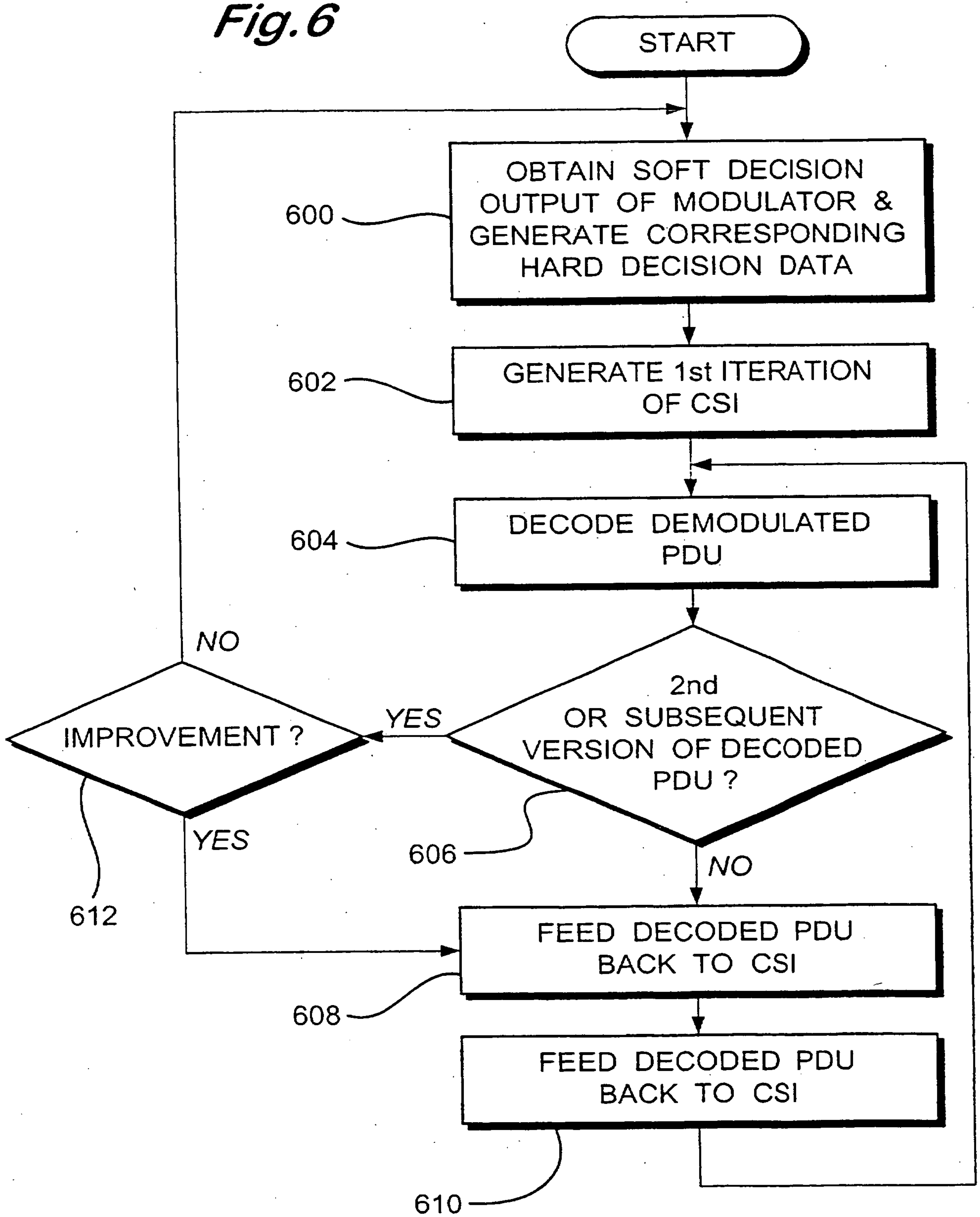
Fig.4



$L_{2,e}$ extrinsic information from dec. 2
514
518
Interleaved version of $L_{1,e}$
516
512
510
400
522
Decoded bits
520
Interleaved version of $L_{2,e}$
508
$L_{1,e}$ extrinsic information from dec. 1
400
504
$Y_{1,n}$ parity
500
502
506
X_n info
$Y_{2,n}$ parity
408
501

Fig.5

Fig. 6


START
OBTAIN SOFT DECISION OUTPUT OF MODULATOR & GENERATE CORRESPONDING HARD DECISION DATA
600
GENERATE 1st ITERATION OF CSI
602
DECODE DEMODULATED PDU
604
2nd OR SUBSEQUENT VERSION OF DECODED PDU ?
606
YES
NO
IMPROVEMENT ?
612
NO
YES
FEED DECODED PDU BACK TO CSI
608
FEED DECODED PDU BACK TO CSI
610

CHANNEL STATE INFORMATION ESTIMATION APPARATUS AND METHOD THEREFOR

The present invention relates to a channel state information estimation apparatus and method therefor of the type used in digital communication systems, for example cellular telecommunication systems, such as a Universal Mobile Telecommunications System (UMTS).

In a cellular telecommunications system, it is known to transmit digital signals between a base station and a mobile terminal using conventional codes, for example convolutional and concatenated codes, to reduce errors caused by channel losses. Recently, the conventional codes have been replaced by the introduction of turbo-codes having improved performance.

Consequently, it is known to decode digital signals received by the mobile terminal using a turbo-code decoder. An estimate of Channel State Information (CSI) is required for iterative decoding of the turbo-codes, the iterative decoding being based upon a Maximum A Posteriori (MAP) probability algorithm, because the actual state of the channel is unknown. Therefore, the estimated CSI constitutes one of a number of inputs to the turbo-code decoder.

Simulations have shown that the performance of MAP probability decoding algorithms implemented in known turbo-code decoders are extremely dependant upon CSI estimates, i.e. performance, for example bit error rate, degradation is observed when the CSI is not known accurately enough. Additionally, it is desirable to reduce the processing time of the turbo-code decoder.

It is therefore an object of the present invention to obviate or at least mitigate the above-described disadvantages.

According to the present invention there is provided a channel state information estimation apparatus comprising an estimator unit arranged to execute an estimation algorithm in response to input data, the input data comprising soft input data and encoded decoded bits fed back from a decoder unit via an encoder unit, the estimator unit being arranged to generate channel state information in response to the input data.

Preferably, the input data further comprises hard decision data for generating channel state information for a first iteration of the decoder unit.

Preferably, the encoder unit is a turbo-code encoder.

Preferably, the decoder unit is a turbo-code decoder.

Preferably, the estimation algorithm is a Minimum Variance Unbiased (MVU) algorithm.

According to the present invention there is also provided a turbo decoder comprising the channel state information estimation apparatus hereinbefore described.

According to the present invention there is also provided a communications terminal comprising the channel state information estimation apparatus hereinbefore described.

The communications terminal may be a mobile terminal.

The communications terminal may be a base station.

According to the present invention, there is also provided a method of generating channel state information for a turbo-code decoder comprising the steps of: receiving decoded bits for channel state information estimation; encoding the decoded bits, and generating an estimate of channel state information in response to the encoded decoded bits.

Preferably, hard decision data is used in place of the encoded decoded bits for a first iteration of a decoder unit used to generate the decoded bits.

Preferably, the decoded bits are generated by a turbo-code decoder.

Preferably, the decoded bits are encoded by a turbo-code encoder.

It is thus possible to provide a channel state information estimation apparatus capable of providing channel state information with greater accuracy. Consequently, turbo-code decoders coupled to the channel state information estimation apparatus according to the present invention perform fewer iterations in order to decode a bit. Thus, the time taken by the turbo-code decoder to process bits is reduced. Additionally, the reliability of data bits decoded by the turbo-code decoder is improved.

At least one embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of apparatus constituting a telecommunications link between a cellular mobile terminal and a "fixed-line" terminal;

Figure 2 is a schematic diagram of a subscriber terminal having a channel state estimator constituting an embodiment of the invention;

Figure 3 is a schematic diagram of a base station having a channel state estimator constituting an embodiment of the invention;

Figure 4 is a schematic diagram of a turbo-code decoder;

Figure 5 is a schematic diagram of the channel state estimation loop used by apparatus of Figures 1 to 4, and

Figure 6 is a flow diagram of a method employed by the apparatus of Figures 1 to 5.

In a cellular network supported by a cellular telecommunications system, for example, a UMTS 100 (Figure 1), a base station 102 supports a geographical area, or cell 104, the base station 102 being in communication with a mobile subscriber unit 106 via a radio frequency (RF) interface 108.

Communications between the base station 102 and a Public Switched Telecommunications Network 110 can be supported by any telecommunications architecture 112 known in the art. A fixed-line telephone 114 is also coupled to the PSTN 110.

It should be appreciated that although reference has been made above to particular types of terminals, other terminals can be used instead of the base station 102 or the mobile subscriber unit 106, including, for example, fixed cellular terminals, or laptop computers/PDAs suitably adapted to function within the UMTS 100. Similarly, although a fixed-line telephone 114 has been described above, other communications devices and links are envisaged, for example, a personal computer (PC) and a modem, or another mobile subscriber unit.

Referring to Figure 2, the mobile subscriber unit 106 comprises a terminal antenna 200 coupled to a terminal duplexer 202. A first terminal of the terminal duplexer 202 is coupled to a terminal Digital Signal Processor (DSP) 204 via a terminal transmitter chain 206. Similarly, a second terminal of the terminal duplexer 202 is coupled to the terminal DSP 204 via a terminal receiver chain 208. The terminal DSP 204 is coupled to a terminal Random Access Memory (RAM) 210, a display 212, for example, a liquid crystal display, a speaker unit 214, a keypad 216 and a microphone 218.

The base station 102 (Figure 3) comprises a base station antenna 300 coupled to a base station duplexer 302. A first terminal of the base station

duplexer 302 is coupled to a base station DSP 304 via a base station transmitter chain 306. Similarly, a second terminal of the base station duplexer 302 is coupled to the base station DSP 304 via a base station receiver chain 308.

The base station DSP 304 is coupled to a base station RAM 310. Information is communicated to and from other parts of the cellular network (not shown) by means of an I/O interface 312 coupled to the base station microprocessor 304.

Referring to Figure 4, the terminal DSP 204 and the base station DSP 304 are each arranged to provide the CSI estimation module 400 comprising a CSI estimator unit 402 having a first input terminal for receiving demodulated data. A first output terminal of the CSI estimator unit 402 is coupled to an input terminal of a first CSI channel de-interleaver 404 arranged to de-interleave data, and a second output terminal of the CSI estimator unit 402 is coupled to an input terminal of a second CSI channel de-interleaver 406 arranged to de-interleave CSI. An output terminal of the first de-interleaver 404 is coupled to a turbo-code decoder 500 by a data bus 408 for carrying the de-interleaved data stream X_n and the de-interleaved parity data $Y_{1,n}$, $Y_{2,n}$. An output terminal of the second de-interleaver 406 is also coupled to the turbo-code decoder 500 by a CSI bus 410, for carrying the CSI. The output terminal of the turbo-code decoder 500 is coupled to a first terminal of a switch 412. A second terminal of the switch 412 is coupled to an input terminal of a turbo-code encoder 414, an output terminal of the turbo-code encoder 414 being coupled to an input terminal of a CSI channel interleaver 416. An output terminal of the channel interleaver 416 is coupled to a second input terminal of the CSI estimator unit 402. Decoded bits are present at the third terminal of the switch 412.

The turbo-code decoder circuit 500 can be either "hard-wired" into each DSP 204, 304, implemented in software, or a combination of both.

It should be appreciated that both the terminal DSP 204 and the base station DSP 304 can each be arranged to provide turbo-code encoder circuits for transmission of data. However, the present invention does not relate to turbo-code encoders per se and so no further reference will be made to turbo-code encoders for transmission of data.

Referring to Figure 5, the turbo-code decoder circuit 500 comprises a first input terminal 502, a second input terminal 504 and a third input terminal 406. The first, second and third input terminals 502, 504, 506 are coupled to a demultiplexer 501 which demultiplexes demodulated data corresponding to Packet Data Units (PDUs) received via the data bus 408 by either the mobile subscriber unit 106 or the base station 102.

The data corresponding to the PDUs comprises three data streams: an information data stream X_n constituting an actual communication, a first stream of parity data $Y_{1,n}$ associated with the information data stream X_n, and a second stream of parity data $Y_{2,n}$ associated with the interleaved information data stream X_n. The parity data $Y_{1,n}$ and $Y_{2,n}$ constitute redundancy introduced by a turbo-code encoder. The data constituting the PDUs present at the first, second and third input terminals 502, 504, 506 are known as soft decision data. As is known in the art, soft decision data is raw, unprocessed, data which has not been converted to logical binary values. In contrast, hard decision data is the processed form of the soft decision data, i.e. the data has been converted to logical binary values.

The first and second input terminals 502, 504 are coupled to respective first and second input terminals of a first MAP decoder 508, the first input

terminal 502 also being coupled to a second MAP decoder 514 via a first interleaver unit 510. The first MAP decoder 508 is coupled to a CSI estimation module 400 and has an output terminal coupled to a second interleaver unit 512, the second interleaver unit 512 and the third input terminal 506 also being coupled to the second MAP decoder 514. The second MAP decoder 514 is also coupled to the CSI estimation module 400. A first output terminal of the second MAP decoder 514 is coupled to a third input terminal of the first MAP decoder 508 via a first de-interleaver unit 516. The second and third input terminals 504, 506 provide demodulated and demultiplexed streams of parity data $Y_{1,n}$, $Y_{2,n}$ associated with the demodulated data described above. A second output terminal of the second MAP decoder 514 is coupled to a decision unit 520 via a second de-interleaver unit 518.

The demodulator (not shown) generates soft decision outputs which comprise binary data symbols $d_1, \ldots, d_N$, $d_n \in \{-1, +1\}$ and a noise component. The noise component consists of real-value samples $n_1, n_2, \ldots, n_N$, the mean of which is generally 0. The covariance matrix of the noise component of the soft decision outputs due to the de-interleaving process after the demodulator (not shown), but before the turbo-code decoding by the turbo-code decoder 400 is given by:

$$R_n = \sigma^2 I_N \qquad (1)$$

Where σ^2 is the variance of the noise and I_N is an N x N identity matrix. The soft decision outputs of the demodulator are real-value samples $\hat{d}_1, \hat{d}_2, \ldots, \hat{d}_N$. Each real-value sample is defined by the following equation:

$$\hat{d}_n = \mu \cdot d_n + n_n \qquad (2)$$

where μ is the average fading attenuation introduced by the channel. Both the mean μ and the variance σ^2 constitute the CSI. The CSI estimator unit 501 estimates the values of the mean μ and the variance σ^2 using a Minimum Variance Unbiased (MVU) estimation technique. The MVU estimation technique yields an estimated mean μ and an estimated variance σ^2 according to the following equation:

$$\begin{pmatrix} \hat{\mu} \\ \hat{\sigma}^2 \end{pmatrix} = \begin{pmatrix} \frac{1}{N}\sum_{n=1}^{N} d_n \cdot \hat{d}_n \\ \frac{1}{N-1}\sum_{n=1}^{N}\left(d_n \cdot \hat{d}_n - \frac{1}{N}\sum_{n=1}^{N} d_n \cdot \hat{d}_n \right) \end{pmatrix} \tag{3}$$

During normal operation of the turbo-code decoder 400, the PDUs (having a predetermined length depending upon a service being provided, for example 64 kbps or 144 kbps) are demodulated by the demodulator (not shown) and demultiplexed by the demultiplexer 401.

Referring to Figure 6, demodulated PDUs are obtained and demultiplexed by the turbo-code encoder circuit 500, the CSI estimation module 400 also obtaining demodulated PDUs constituting soft decision data (step 600). When a transmitted PDU is received, decoded bits are not available to the CSI estimation module 400, and so the CSI estimator unit 402 generates (step 600) hard decision data based upon the soft decision data. Both the hard decision data and the soft decision data are used by the CSI estimator unit 402 to generate (step 602) a first iteration model of the CSI using the MVU technique. The CSI generated by the CSI estimator unit 402 is used by the turbo-code decoder 500 to decode (step 604) the transmitted PDU received from the first input terminal 502. The turbo-code decoder 500 decodes (step 604) the transmitted PDU using the MAP probability algorithm known in the art, the decoding process using a

number of iterations to decode the transmitted PDU, i.e. to generate an estimate of the transmitted PDU. Once the transmitted PDU has been decoded, the turbo code decoder determines whether the decoded transmitted PDU constitutes a second or subsequent estimate of the transmitted PDU (step 606). If the decoded transmitted PDU is a first estimate of the transmitted PDU, the decoded transmitted PDU is fed back (step 608) to the CSI estimator unit 402 via the turbo-code encoder 414 and the CSI channel interleaver 416. If the decoded transmitted PDU constitutes a second or subsequent estimate of the transmitted PDU, the turbo-code decoder 500 determines whether the second or subsequent estimate of the transmitted PDU is an improvement over an immediately previous estimate of the decoded transmitted PDU (step 612). If the second or subsequent estimate of the transmitted PDU is an improvement over an immediately previous estimate of the transmitted PDU, the decoded transmitted PDU is fed back (step 608) to the CSI estimator unit 402 via the turbo-code encoder 414 and the channel interleaver 416. The decoded transmitted PDU, i.e. a decoded bit-stream constituting the transmitted PDU, fed back to the CSI estimator unit 402 is used by the MVU estimation technique to generate a refined CSI (step 610). The refined CSI is then used by the turbo-code decoder 500 to decode the transmitted PDU again in order to generate an improved decoded transmitted PDU. Once no further improvement can be made to the decoding of the transmitted PDU (step 612), a subsequent transmitted PDU is taken from the first input terminal 502 for decoding, and the above process is repeated (steps 600 to 612).

Each set of iterations of the turbo-code decoder 500 constituting an estimate of the transmitted PDU results in decoded bits having improved

reliability. Consequently, the MVU estimation technique is also capable of providing more accurate CSI.

CLAIMS

1. A channel state information estimation apparatus comprising an estimator unit arranged to execute an estimation algorithm in response to input data, the input data comprising soft input data and encoded decoded bits fed back from a decoder unit via an encoder unit, the estimator unit being arranged to generate channel state information in response to the input data.

2. An apparatus as claimed in Claim 1, wherein the input data further comprises hard decision data for generating channel state information for a first iteration of the decoder unit.

3. An apparatus as claimed in Claim 1 or Claim 2, wherein the encoder unit is a turbo-code encoder.

4. An apparatus as claimed in any one of the preceding claims, wherein the decoder unit is a turbo-code decoder.

5. An apparatus as claimed in any one of the preceding claims, wherein the estimation algorithm is a Minimum Variance Unbiased (MVU) algorithm.

6. A turbo-code decoder comprising the channel state information estimation apparatus as claimed in any one of the preceding claims.

7. A communications terminal comprising the channel state information estimation apparatus as claimed in any one of Claims 1 to 6.

8. A communications terminal as claimed in Claim 7, wherein the communications terminal is a mobile terminal.

9. A communications terminal as claimed in Claim 7, wherein the communications terminal is a base station.

10. A method of generating channel state information for a turbo-code decoder comprising the steps of:

receiving decoded bits for channel state information estimation;

encoding the decoded bits, and

generating an estimate of channel state information in response to the encoded decoded bits.

11. A method as claimed in Claim 10, wherein hard decision data is used in place of the encoded decoded bits for a first iteration of a decoder unit used to generate the decoded bits.

12. A method as claimed in Claim 10 or Claim 11, wherein the decoded bits are generated by a turbo-code decoder.

13. A method as claimed in any one of Claims 10 to 12, wherein a turbo-code encoder encodes the decoded bits.

14. A channel state information estimation apparatus substantially as hereinbefore described with reference to Figure 5.

15. A method of generating channel state information substantially as hereinbefore described with reference to Figure 6.

The Patent Office

INVESTOR IN PEOPLE

Application No: GB 0006181.2	**Examiner:** Owen Wheeler
Claims searched: 1-15	**Date of search:** 22 September 2000

14

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H4P (PRE, PRV)

Int Cl (Ed.7): H03M: 13/29, 13/39, 13/41, 13/45; H04L: 1/00, 25/02, 25/03

Other: Online: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2271916 A	[ROKE MANOR RESEARCH] See Fig. 6 and page 12 para 2 to page 14 para 2.	1-13
X	EP 0948140 A1	[LUCENT TECHNOLOGIES] See Figs. 1 and 2 and column 5 lines 10-44.	1-13
X	EP 0802656 A2	[WAVECOM] See Fig. 3 and page 9 line 42 to page 10 line 22.	1-13
A	EP 0550143 A2	[AT&T] See Fig. 12 and page 10 lines 21-44.	
A	US 5285480 A	[CHENNAKESHU] See Fig. 5	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.